LEAD SOIL TREND ANALYSIS
THROUGH MARCH, 2005
EVALUATION BY INDIVIDUAL QUADRANT
Herculaneum Lead Smelter Site
Herculaneum, Missouri

Tetra Tech EM Inc. (Tetra Tech) was tasked by the U.S. Environmental Protection Agency (EPA) Region 7 Enforcement/Fund Lead Removal program to conduct a trend analysis of soil lead concentrations at selected locations within Herculaneum, Missouri (City). Specifically, the Tetra Tech Superfund Technical Assessment and Response Team (START) 2 was requested to review and analyze data that would enable EPA to determine if soil lead concentrations were increasing over time at a variety of locations within the City. Tetra Tech was requested to 1) perform a trend analysis for individual quadrants within each yard using the most current sampling data, and 2) estimate the range of monthly increase in lead concentrations for properties grouped into three categories based on distance from the smelter (less than or equal to 025 mile, 0.25 to 0.50 miles, and 0.50 to 0.75 miles). The assessment was conducted under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 and the Superfund Amendments and Reauthorization Act of 1986. The project was assigned under START Contract No. 68-S7-01-41, Task Order No. 0027.

Tetra Tech focused its analysis on one data set called "Recontamination." This data set includes results from a number of residential properties. The data were collected from four different quadrants at each property, and additional data for several properties came from samples collected in driveway areas outside the quadrants. Lead concentrations were estimated at each location at approximately monthly intervals from the time removal activities were completed until March 2005 (sampling round 20). Due to the sequence of removal activities, not all properties underwent the same number of sampling events; the number of events ranged from 6 to 14 events per quadrant for individual properties. At many locations, some intervals within the series were omitted because of weather or access restrictions. The lead concentrations were determined by use of a portable X-ray fluorescence (XRF) instrument. Samples were collected and analyzed in accordance with the quality assurance project plan (QAPP) dated September 11, 2001.

This document presents the methods used to evaluate changes in soil lead concentrations following the removal activities, and the results of this analysis.

Methods

Temporal trends in lead concentrations for 17 properties are summarized in Table 1. Trend tests were conducted for each property using all data collected from round 7 (August 2002) through round 20 (March 2005). The non-parametric Mann-Kendall test was used to evaluate temporal trends for each sampled quadrant at the individual properties. The Mann-Kendall test is a widely used statistical test for detecting monotonic trends (that is, trends that are either increasing or decreasing) in time-series of data (Gilbert 1987; Helsel and Hirsch 1992; Gibbons 1994). Because the Mann-Kendall test uses only the relative magnitude of the data rather than their measured values, it has a number of desirable properties: the data need not be normally distributed; and the test is not significantly affected by outliers, missing data, or censored data. Censored data are treated in the Mann-Kendall test by setting all non-detect values to a concentration slightly below the minimum detected concentration.

For all properties where at least one quadrant showed a significant increasing trend based on the Mann-Kendall test, linear regression analysis was performed to estimate the monthly increase in lead concentration. This analysis was performed to provide rough estimates of the range of potential increase in lead concentrations for properties grouped according to distance from the smelter. Three distance categories were evaluated: less than or equal to 0.25 mile, 0.25 to 0.50 mile, and 0.50 to 0.75 mile. Because the purpose of this analysis was to only provide rough estimates of the rate of change in lead concentration, simple linear regression was performed on the untransformed data. Certain evaluation methods and diagnostic tools that are commonly used in linear regression analysis (e.g., evaluation of different transformations of the data, verification of model assumptions, and evaluation of outliers) were not used in this analysis.

Results

The analysis of the temporal trends in lead concentrations identified 16 of the 17 properties containing at least one quadrant with a statistically significant increasing trend: House Numbers 20, 101, 102, 5, 6, 22, 24, 12, 17, 21, 16, 19, 9, 18, 3, and 7. Five properties had temporal trends with increasing lead concentrations in all four quadrants: House Numbers 20, 5, 12, 17, and 9. Two properties had temporal trends with increasing lead concentrations in three of four quadrants: House Numbers 22 and 7. Seven properties had temporal trends with increasing lead concentrations in two of four quadrants: House

Numbers 101, 102, 24, 21, 16, 19, and 3. House numbers 6 and 18 had only one quadrant that showed a statistically significant increasing trend in lead concentration. Only one property, House Number 76, showed no statistically significant trend in lead concentrations, although only two quadrants were evaluated.

The results of linear regression analysis performed on properties that showed a significant increasing trend in lead concentration in at least one quadrant are provided in Table 2. The slope, intercept, standard error of the slope, and two-sided 95 percent confidence intervals for the slope estimates were calculated for 39 quadrants within 15 properties. Ranges for the monthly rates of increase in lead were 1.64 to 24.32 milligrams per kilogram (mg/kg)-month, -1.83 to 4.19 mg/kg-month, and 0.64 to 9.79 mg/kg-month, respectively, for properties located less than or equal to 0.25 mile, 0.25 to 0.50 mile, and 0.50 to 0.75 mile from the smelter. The upper 95 percent confidence limit for the monthly rate of increase was also evaluated to estimate maximum potential rates of increase. Because of the variability in the individual estimates, the 50^{th}, 75^{th}, and 90^{th} percentiles of the distribution of the individual upper confidence limits within each distance category are also reported in Table 2. The 75^{th} and 90^{th} (in parentheses) percentile values for the monthly rate of increase for the properties grouped according to increasing distance from the smelter are 11.30 (25.78), 5.65 (27.23), and 4.4 (18.01) mg/kg-month. It should be cautioned that these are considered rough estimates only, as no attempt was made to evaluate the validity of the regression model assumptions, or the uncertainty associated with the predicted rates of increase.

References:

Gibbons, R. D. 1994. *Statistical Methods for Groundwater Monitoring.* John Wiley & Sons, Inc. New York, New York.

Gilbert, R. O. 1987. *Statistical Methods in Environmental Pollution Monitoring.* John Wiley & Sons, Inc. New York, New York.

Helsel, D. R. and R. M. Hirsh. 1992. *Statistical Methods in Water Resources.* Elsevier. New York, New York.

TABLE 1
RESULTS OF STATISTICAL TESTING FOR MONOTONIC TRENDS (MANN-KENDALL TEST) IN LEAD CONCENTRATION INDIVIDUAL QUADRANTS FOR SAMPLING ROUNDS 7 THROUGH 20 HERCULANEUM LEAD SMELTER SITE - HERCULANEUM, MISSOURI

Distance From Smelter[1]	House Number	Quadrant	Number of Sampling Events[2]	Number of Detected Samples	Sampling Event		Mann-Kendall Test Statistic[3] (S)	Probability > S	Trend Significant?[4] (Yes/No)	Direction of Trend
					First	Last				
0.10	76	Q1	7	7	10/30/2003	03/29/2005	11	0.068	No	NA
		Q2	7	7	10/30/2003	03/29/2005	9	0.119	No	NA
0.20	20	Q1	13	13	08/26/2002	03/30/2005	50	0.002	**Yes**	**Increasing**
		Q2	13	13	08/26/2002	03/30/2005	46	0.005	**Yes**	**Increasing**
		Q3	13	13	08/26/2002	03/30/2005	56	0.001	**Yes**	**Increasing**
		Q4	13	13	08/26/2002	03/30/2005	42	0.009	**Yes**	**Increasing**
	101	Q1	6	6	12/22/2003	03/28/2005	9	0.068	No	NA
		Q2	6	5	12/22/2003	03/28/2005	9	0.068	No	NA
		Q3	6	6	12/22/2003	03/28/2005	13	0.008	**Yes**	**Increasing**
		Q4	6	6	12/22/2003	03/28/2005	13	0.008	**Yes**	**Increasing**
	102	Q1	6	6	12/22/2003	03/30/2005	13	0.008	**Yes**	**Increasing**
		Q2	6	6	12/22/2003	03/30/2005	7	0.136	No	NA
		Q3	6	6	12/22/2003	03/30/2005	13	0.008	**Yes**	**Increasing**
		Q4	6	6	12/22/2003	03/30/2005	7	0.136	No	NA
0.25	5	Q1	13	10	08/26/2002	03/29/2005	52	0.001	**Yes**	**Increasing**
		Q2	13	12	08/26/2002	03/29/2005	56	0.001	**Yes**	**Increasing**
		Q3	13	13	08/26/2002	03/29/2005	51	0.002	**Yes**	**Increasing**
		Q4	13	13	08/26/2002	03/29/2005	44	0.006	**Yes**	**Increasing**
	6	Q1	13	13	08/23/2002	03/30/2005	26	0.062	No	NA
		Q2	13	13	08/23/2002	03/30/2005	46	0.005	**Yes**	**Increasing**
		Q3	13	13	08/23/2002	03/30/2005	10	0.172	No	NA
		Q4	13	13	08/23/2002	03/30/2005	18	0.116	No	NA
	22	Q1	12	12	08/26/2002	03/30/2005	24	0.058	No	NA
		Q2	12	12	08/26/2002	03/30/2005	42	0.004	**Yes**	**Increasing**
		Q3	12	12	08/26/2002	03/30/2005	37	0.009	**Yes**	**Increasing**
		Q4	12	12	08/26/2002	03/30/2005	38	0.008	**Yes**	**Increasing**
	24	Q1	10	10	11/07/2002	03/30/2005	17	0.078	No	NA
		Q2	10	10	11/07/2002	03/30/2005	23	0.023	**Yes**	**Increasing**
		Q3	10	10	11/07/2002	03/30/2005	13	0.146	No	NA
		Q4	10	9	11/07/2002	03/30/2005	28	0.006	**Yes**	**Increasing**

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INDIVIDUAL QUADRANTS FOR SAMPLING ROUNDS 7 THROUGH 20
HERCULANEUM LEAD SMELTER SITE - HERCULANEUM, MISSOURI

Distance From Smelter[1]	House Number	Quadrant	Number of Sampling Events[2]	Number of Detected Samples	Sampling Event		Mann-Kendall Test Statistic[3] (S)	Probability > S	Trend Significant?[4] (Yes/No)	Direction of Trend
					First	Last				
0.40	12	Q1	14	11	08/23/2002	03/28/2005	42	0.016	**Yes**	**Increasing**
		Q2	14	9	08/23/2002	03/28/2005	47	0.007	**Yes**	**Increasing**
		Q3	14	12	08/23/2002	03/28/2005	50	0.005	**Yes**	**Increasing**
		Q4	14	13	08/23/2002	03/28/2005	37	0.029	**Yes**	**Increasing**
	17	Q1	13	13	08/22/2002	03/29/2005	42	0.009	**Yes**	**Increasing**
		Q2	13	13	08/22/2002	03/29/2005	38	0.016	**Yes**	**Increasing**
		Q3	13	13	08/22/2002	03/29/2005	32	0.033	**Yes**	**Increasing**
		Q4	13	11	08/22/2002	03/29/2005	31	0.037	**Yes**	**Increasing**
	21	Q1	9	7	08/23/2002	03/28/2005	15	0.075	No	NA
		Q2	9	9	08/23/2002	03/28/2005	14	0.090	No	NA
		Q3	9	9	08/23/2002	03/28/2005	20	0.022	**Yes**	**Increasing**
		Q4	9	9	08/23/2002	03/28/2005	26	0.003	**Yes**	**Increasing**
0.50	16	Q1	11	7	09/16/2002	03/28/2005	1	0.199	No	NA
		Q2	11	5	09/16/2002	03/28/2005	36	0.002	**Yes**	**Increasing**
		Q3	11	5	09/16/2002	03/28/2005	16	0.088	No	NA
		Q4	11	7	09/16/2002	03/28/2005	33	0.008	**Yes**	**Increasing**
	19	Q1	13	12	08/22/2002	03/29/2005	41	0.010	**Yes**	**Increasing**
		Q2	13	10	08/22/2002	03/29/2005	25	0.067	No	NA
		Q3	13	10	08/22/2002	03/29/2005	21	0.094	No	NA
		Q4	13	12	08/22/2002	03/29/2005	43	0.007	**Yes**	**Increasing**
0.54	9	Q1	13	13	08/22/2002	03/29/2005	37	0.018	**Yes**	**Increasing**
		Q2	13	13	08/22/2002	03/29/2005	31	0.037	**Yes**	**Increasing**
		Q3	13	13	08/22/2002	03/29/2005	36	0.020	**Yes**	**Increasing**
		Q4	13	12	08/22/2002	03/29/2005	33	0.029	**Yes**	**Increasing**
0.60	18	Q1	14	14	08/23/2002	03/28/2005	27	0.072	No	NA
		Q2	14	13	08/23/2002	03/28/2005	17	0.136	No	NA
		Q3	14	14	08/23/2002	03/28/2005	30	0.056	No	NA
		Q4	14	14	08/23/2002	03/28/2005	33	0.043	**Yes**	**Increasing**

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Distance From Smelter[1]	House Number	Quadrant	Number of Sampling Events[2]	Number of Detected Samples	Sampling Event		Mann-Kendall Test Statistic[3] (S)	Probability > S	Trend Significant?[4] (Yes/No)	Direction of Trend
					First	Last				
0.75	3	Q1	14	11	08/23/2002	03/28/2005	4	0.197	No	NA
		Q2	14	12	08/23/2002	03/28/2005	46	0.010	**Yes**	**Increasing**
		Q3	14	13	08/23/2002	03/28/2005	9	0.181	No	NA
		Q4	14	13	08/23/2002	03/28/2005	40	0.020	**Yes**	**Increasing**
0.80	7	Q1	14	14	08/23/2002	03/28/2005	23	0.097	No	NA
		Q2	14	12	08/23/2002	03/28/2005	48	0.007	**Yes**	**Increasing**
		Q3	14	11	08/23/2002	03/28/2005	34	0.038	**Yes**	**Increasing**
		Q4	14	10	08/23/2002	03/28/2005	59	0.001	**Yes**	**Increasing**

Notes:

[1] Properties are ordered as a function of increasing distance from the smelter.

[2] Trend tests were not conducted for properties with fewer than four rounds of sampling.

[3] All censored (nondetect) measurements were set equal to a concentration slightly lower than the minimum detected value

[4] Monotonic trends are significant for probabilities less than or equal to 0.05; significant negative values for the Mann-Kendall test statistic indicate that trends are decreasing; and significant positive values for the Mann-Kendall test statistic indicate that trends are increasing.

NA No significant trend identified.

TABLE 2
RESULTS OF LINEAR REGRESSION ANALYSIS FOR ALL QUADRANTS SHOWING A SIGNIFICANT INCREASING MANN-KENDALL TREND TEST RESULT

Distance From Smelter[1]	House Number	Quadrant	Regression Coefficients for Days Versus Concentration			Monthly Increase (mg/kg-month)	95 Percent Confidence Limits for Monthly Increase in Lead Concentrations		Percentiles for the Distribution of Estimated UCLs within Each Distance Group		
			Intercept	Slope	S.E. (Slope)		LCL	UCL	50	75	90
Less than or Equal to 0.25	20	Q1	82.75	0.17	0.04	5.16	2.36	7.96	7.84	11.30	25.78
		Q2	39.12	0.32	0.08	9.66	4.54	14.79			
		Q3	94.54	0.23	0.05	6.80	3.48	10.11			
		Q4	100.74	0.21	0.06	6.45	2.18	10.72			
	101	Q3	-76.83	0.25	0.03	7.54	4.64	10.44			
		Q4	-97.01	0.27	0.06	8.18	3.32	13.05			
	102	Q1	-71.30	0.81	0.37	24.32	-6.60	55.23			
		Q3	-29.18	0.45	0.11	13.49	4.48	22.51			
	5	Q1	50.86	0.06	0.02	1.91	0.74	3.09			
		Q2	42.42	0.09	0.02	2.85	1.81	3.88			
		Q3	68.82	0.10	0.03	3.00	1.25	4.74			
		Q4	70.27	0.15	0.05	4.59	1.47	7.72			
	6	Q2	77.88	0.13	0.04	3.92	0.99	6.85			
	22	Q2	166.04	0.17	0.05	5.16	2.14	8.18			
		Q3	67.11	0.11	0.04	3.22	0.64	5.80			
		Q4	60.17	0.13	0.04	3.97	1.26	6.68			
	24	Q2	59.68	0.05	0.02	1.64	-0.01	3.28			
		Q4	57.30	0.08	0.02	2.27	0.70	3.83			
0.25 to 0.50	12	Q1	385.07	-0.06	0.74	-1.84	-50.28	46.61	4.54	5.65	27.23
		Q2	35.84	0.14	0.06	4.19	0.53	7.85			
		Q3	61.94	0.05	0.03	1.54	-0.74	3.81			
		Q4	64.23	0.13	0.04	3.79	0.98	6.59			
	17	Q1	69.09	0.06	0.02	1.67	0.25	3.10			
		Q2	59.54	0.10	0.04	3.01	0.67	5.34			
		Q3	88.09	0.02	0.03	0.64	-1.38	2.66			
		Q4	64.38	0.03	0.02	1.04	-0.36	2.44			
	21	Q3	56.89	0.10	0.02	3.13	2.03	4.24			
		Q4	52.30	0.12	0.01	3.72	2.81	4.62			
	16	Q2	58.02	0.13	0.01	3.89	2.88	4.91			
		Q4	87.48	0.10	0.02	3.12	1.52	4.73			
	19	Q1	49.15	0.07	0.02	2.07	0.93	3.21			
		Q4	51.36	0.09	0.03	2.72	0.98	4.46			
0.50 to 0.75	9	Q1	68.57	0.04	0.02	1.20	-0.24	2.65	3.27	4.40	18.01
		Q2	69.60	0.06	0.03	1.90	-0.12	3.92			
		Q3	69.84	0.33	0.12	9.79	1.57	18.01			
		Q4	94.58	0.07	0.03	2.22	0.05	4.40			
	18	Q4	66.46	0.03	0.01	0.79	0.10	1.47			
	3	Q2	49.18	0.06	0.02	1.92	0.58	3.27			
		Q4	52.68	0.02	0.01	0.64	0.05	1.23			

Notes:

mg/kg-month milligram per kilogram of lead per month
LCL Lower confidence limit
S.E. Standard error of estimate
UCL Upper confidence limit